



Boosting Resilience Through Rice-Fish Polyculture in Tropical Agricultural Ecosystems

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Abstract— *Rice-fish polyculture represents an integrated farming system that combines rice cultivation with aquaculture, offering a pathway to enhance agricultural resilience in tropical ecosystems. This review explores the historical evolution, ecological advantages, economic viability, and challenges of rice-fish systems, drawing on global case studies primarily from Asia and Africa. By synthesizing data from over 50 studies, it highlights how these systems improve biodiversity, nutrient cycling, and climate adaptability while reducing reliance on chemical inputs. Comparative analyses reveal increased yields, higher net incomes, and lower environmental impacts compared to monocultures. The article underscores the potential of rice-fish polyculture to foster sustainable food security amid climate change, emphasizing the need for policy support and adaptive management.*

Keywords— *Rice-fish polyculture, tropical agriculture, climate resilience, integrated farming, biodiversity, sustainable aquaculture*

I. INTRODUCTION

Tropical agricultural ecosystems face mounting pressures from climate variability, population growth, and resource scarcity. Rice, a staple crop for billions, dominates these landscapes, but conventional monoculture practices often exacerbate environmental degradation through excessive fertilizer and pesticide use [1]. Rice-fish polyculture emerges as a resilient alternative, integrating fish farming into rice paddies to create symbiotic systems that boost productivity and ecological stability [2]. This approach not only diversifies outputs but also enhances system resilience by mitigating risks associated with floods, droughts, and pests [3].

In tropical regions, where rice cultivation covers vast areas, incorporating fish like tilapia, carp, or prawns leverages natural synergies. Fish control weeds and insects, while their waste fertilizes rice, reducing input costs and pollution [4]. Historically rooted in ancient Asian practices, rice-fish systems have evolved into modern strategies for sustainable development [5]. This review examines their historical context, benefits, challenges, and comparative performance, drawing on empirical data to advocate for wider adoption in tropical agroecosystems.

II. HISTORICAL DEVELOPMENT OF RICE-FISH POLYCULTURE

The origins of rice-fish polyculture trace back over 2,000 years, emerging in continental Asia as communities adapted to wetland environments [6]. Archaeological evidence from Han Dynasty tombs in China reveals clay models of rice paddies with fish, indicating early integration [7]. In southern China, farmers released excess carp fry into rice fields during the Shang Dynasty (circa 1400-1154 BCE), marking the co-evolution of rice and fish farming [8].

By the medieval period, rice-fish culture spread across Southeast Asia, including Japan, Indonesia, and Thailand [9] [10]. In Japan, it gained prominence in the 1840s in the Saku basin, expanding during World War II for food security [11]. Similarly, in India and Vietnam, indigenous practices combined rice with wild fish capture, evolving into intentional stocking [12].

The 20th century saw fluctuations: post-1950s chemical-intensive rice farming diminished traditional systems in China due to pesticides and planned economies [13]. However, economic reforms in the late 1970s revived interest, with farmers resuming practices for household

protein [14]. Globally, organizations like FAO and IRRI promoted rice-fish integration from the 1980s, recognizing its role in poverty alleviation [15].

In Africa, adoption is more recent, influenced by Asian models. Early trials in the 1950s introduced carp into rice fields in Madagascar and Egypt, but widespread implementation began in the 1990s through development projects [16] [17]. Today, rice-fish systems in tropical Africa, such as in Burkina Faso and Mali, build on these foundations, adapting to local climates [18].

This historical trajectory underscores rice-fish polyculture's adaptability, transitioning from subsistence to a tool for resilience in modern tropical agriculture [19] [20].

Ecological Benefits and Mechanisms

Rice-fish polyculture fosters ecological synergies that enhance tropical agroecosystem health. Fish reduce pests by

24-68%, weeds by 58-68%, and diseases like sheath blight, minimizing pesticide needs by up to 68% [2] [21]. In return, rice shades water, lowering temperatures by 2.56°C and boosting fish activity by 58% [2].

Nutrient cycling is optimized: fish excrete nitrogen and phosphorus, improving soil fertility and rice nitrogen-use efficiency by 6% [22]. This reduces fertilizer inputs by 24% and nitrogen losses, curbing eutrophication [23]. Biodiversity surges, with increased earthworm and arthropod populations supporting natural pest control [24].

In tropics, these systems mitigate environmental impacts. Methane emissions drop by 30% due to fish aeration, aiding climate goals [25]. Water quality improves via oxygenation and reduced organics [26]. Compared to monocultures, rice-fish fields emit less CH₄ and N₂O, with 35.72% higher ecosystem service values [4].

Table 1 compares pest and weed reductions across studies:

Study	Location	System	Pest Reduction (%)	Weed Reduction (%)	Reference
Xie et al. (2011)	China	Rice-Fish	24 (Planthoppers)	58-68	[2]
Wan et al. (2019)	Thailand	Rice-Fish	24.07 (Herbivores)	68	[21]
Cui et al. (2023)	Indonesia	Rice-Fish	12 (Insects)	58	[22]
Ibrahim et al. (2021)	Africa	Rice-Fish	20 (Pests)	50	[58]

These mechanisms position rice-fish polyculture as a cornerstone for tropical ecological sustainability [27].

Economic Viability and Social Impacts

Economically, rice-fish systems outperform monocultures, yielding 4-25% higher rice and 400-600 kg/ha fish, with net returns 45-270% greater [28] [29]. In Bangladesh, incomes

rise 9-132% [30]. Diversification buffers risks, with BCRs up to 2.09 [31].

Socially, it bolsters food security by providing protein, reducing malnutrition [32]. In rural tropics, it empowers women through diversified labor and generates employment [33]. Health benefits include lower mosquito-borne diseases via fish predation [34].

Table 2 Outlines economic comparisons:

System	Net Return (USD/ha)	BCR	Region	Reference
Rice Monoculture	290-550	1.0-1.2	Bangladesh	[35]
Rice-Fish (Low Input)	844-1142	1.5-2.0	China	[28]
Rice-Fish (High Input)	2634	2.03	Vietnam	[29]
Rice-Shrimp	2120	1.8	Indonesia	[36]

These gains make rice-fish polyculture vital for tropical livelihoods [37].

Challenges in Implementation

Despite benefits, challenges persist. High initial costs for field modifications deter adoption [38]. Water scarcity in drier tropics limits viability [39]. Pests and diseases require careful management, as excessive fish density can harm rice [40].

Technical knowledge gaps hinder success; farmers need training [41]. Climate extremes like floods erode fields [42]. Market access for fish remains limited in remote areas [43].

Policy barriers include inadequate subsidies and regulations favoring monocultures [44]. In Africa, land tenure issues complicate scaling [45].

Addressing these through extension services and incentives is crucial [46].

Case Studies from Asia and Africa

In China's Qingtian terraces, rice-fish systems sustain yields with low inputs for over 1,200 years, reducing pests naturally [2]. In Vietnam's Mekong Delta, rice-shrimp alternations boost incomes by 50% amid salinity intrusion [47].

In Bangladesh, community-managed systems yield 1-2.25 t/ha fish alongside rice, enhancing nutrition [29].

Indonesia's minapadi system integrates carp, yielding 12% more rice [48].

In Africa's Burkina Faso, trials show 6% fish growth increases and 300 USD/ha higher net income [49]. Mali's systems improve soil fertility, yielding 300-600 kg/ha fish [45]. Kenya's Lake Victoria basin adapts tilapia, boosting resilience [50].

These cases illustrate adaptability across tropics [42].

Table 3 compares yields

Region	Rice Yield Increase (%)	Fish Yield (kg/ha)	Reference
China	4.14	400-600	[22]
Vietnam	12	600-800	[43]
Bangladesh	4-25	750-2250	[28]
Africa (Mali)	6	300-600	[45]

Climate Resilience in Rice-Fish Systems

Rice-fish polyculture enhances resilience to climate stressors. In flood-prone areas, fish survive inundation, providing income when rice fails [51]. Drought-tolerant designs with refuges maintain production [39].

Reduced emissions (30% less methane) and carbon sequestration via improved soils mitigate warming [52].

Biodiversity buffers shocks, with fish aiding recovery post-extremes [53].

In Cambodia's Tonle Sap, systems increase yields by 57% and resilience scores [54]. Nigeria's northern regions report 132% income gains amid variability [55].

Table 4 compares resilience metrics

Metric	Monoculture	Polyculture	Improvement (%)	Reference
Yield Stability	Low	High	20-30	[1]
GHG Emissions	High	Low	30 Reduction	[25]
Water Use Efficiency	Moderate	High	25	[56]
Income Resilience	Variable	Stable	50-132	[30]

These attributes make rice-fish systems ideal for tropical climate adaptation [57].

III. CONCLUSION

In the crucible of tropical agriculture, where climate volatility, soil depletion, and burgeoning populations converge to threaten food sovereignty, rice-fish polyculture stands as a profound testament to human ingenuity and ecological harmony. This integrated system, far from a mere farming technique, embodies a regenerative ethos that bridges ancient agrarian wisdom with the imperatives of modern sustainability. From the mist-shrouded terraces of China's Qingtian County, where these practices have endured for over 1,200 years, to the sun-baked paddies of Burkina Faso and the monsoon-swept deltas of Vietnam, rice-fish polyculture weaves a resilient fabric capable of withstanding the tempests of global change. It transforms

vulnerability into vitality, turning flooded fields into bountiful havens and drought-scarred lands into oases of dual harvest.

At its core, the system's brilliance lies in symbiosis: rice plants arch gracefully over shallow waters, their roots ensnaring nutrients while providing dappled shade that tempers the relentless tropical sun, cooling waters by up to 2.56°C and invigorating fish metabolism. In reciprocity, species like tilapia, common carp, and prawns become vigilant guardians, devouring pests and weeds with an efficiency that slashes chemical pesticide reliance by 68% and herbicide needs by 58-68%. This biological ballet extends to nutrient dynamics, where fish excretions—rich in nitrogen and phosphorus—supercharge soil fertility,

elevating rice nitrogen-use efficiency by 6% and curtailing fertilizer inputs by 24%. The result? A virtuous cycle that not only boosts rice yields by 4-25% and delivers 300-2,250 kg/ha of protein-packed fish but also amplifies biodiversity, summoning earthworms, arthropods, and microbial allies to fortify the ecosystem against collapse.

Economically, rice-fish polyculture is a bulwark against precarity. Net returns surge 45-270%, with benefit-cost ratios climbing to 2.09, offering smallholders a diversified income stream that buffers against crop failures or market slumps. In Bangladesh, households report 9-132% income uplifts; in Mali, an additional 300 USD/ha materializes from fish sales alone. This financial fortitude cascades into social upliftment, fortifying food security with accessible, nutrient-dense proteins that combat stunting and micronutrient deficiencies afflicting millions in rural tropics. Women, often sidelined in monoculture drudgery, find agency in multifaceted roles—from fingerling stocking to market bargaining—while communities coalesce around shared ponds, fostering social cohesion and slashing mosquito populations through predatory foraging, thereby curbing malaria's toll.

Yet, resilience is no panacea without confronting headwinds. Initial infrastructural hurdles, such as dike reinforcements or refuge trenches, exact upfront costs that daunt resource-poor farmers. Water scarcity in semi-arid zones, knowledge voids in fish husbandry, and policy biases toward chemical-intensive monocrops erect barriers to scale. Floods erode bunds, while tenuous fish markets in remote hinterlands undermine viability. Case studies illuminate antidotes: Vietnam's adaptive rice-shrimp rotations defy salinity surges, yielding 50% income gains; Kenya's tilapia integrations around Lake Victoria enhance post-flood recovery. These narratives underscore the imperative of tailored interventions—farmer field schools, microfinance for pond retrofits, and subsidies that incentivize polyculture over extractive paradigms.

Looking horizonward, rice-fish polyculture heralds a blueprint for climate-smart agriculture. By aerating sediments and pruning methane emissions 30%, it aligns with Paris Agreement ambitions, sequestering carbon in revitalized soils while honing water-use efficiency by 25%. Yield stability soars 20-30%, and income resilience holds firm amid extremes, as evidenced in Cambodia's 57% productivity leaps. In Nigeria's north, 132% gains amid erratic rains affirm its adaptive prowess. To unlock this potential, stakeholders must converge: governments to enact land-tenure reforms and extension networks; NGOs to seed pilot hubs; researchers to breed climate-hardy strains. International bodies like FAO can amplify through

knowledge exchanges, ensuring equitable diffusion across the Global South.

Ultimately, rice-fish polyculture transcends production metrics; it reimagines human-nature relations in tropical heartlands. It invites us to cultivate not just crops, but covenants—with the land that sustains, the waters that nourish, and the communities that steward. In an era where monocultures sow seeds of fragility, this polycultural paradigm harvests hope: diverse, durable, and deeply rooted. By embracing it, tropical ecosystems—and the billions they cradle—can flourish, turning peril into prosperity, scarcity into surplus, and uncertainty into enduring abundance. The paddy, once a solitary stage, becomes a symphony of life, echoing the timeless rhythm of resilience.

REFERENCES

- [1] Freed, S., McCartney, M., Akester, M., Dubois, M., Kura, Y., & Thilsted, S. H. (2020). Maintaining diversity of integrated rice and fish production confers adaptability of food systems to global change. *Frontiers in Sustainable Food Systems*, 4, Article 576179. <https://doi.org/10.3389/fsufs.2020.576179>
- [2] Zhang, Y., Wang, C., & Hu, S. (2023). Rice-animal co-culture systems benefit global sustainable intensification of agriculture. *Earth's Future*, 11(2), Article e2022EF002984. <https://doi.org/10.1029/2022EF002984>
- [3] Ji, Z. J., Li, S. X., Wang, J., Zhao, P., Li, K. Q., He, X. Y., Li, J. J., Liu, B., He, Y., Zhang, X. P., & Jiang, L. (2023). Coculturing rice with aquatic animals promotes ecological intensification of paddy ecosystem. *Journal of Plant Ecology*, 16(6), Article rtad014. <https://doi.org/10.1093/jpe/rtad014>
- [4] Liu, D., Li, S., Li, K., Zhao, P., & Jiang, L. (2021). Ecosystem services analysis for sustainable agriculture expansion: Rice-fish co-culture system breaking through the Hu Line. *Ecological Indicators*, 124, Article 107405. <https://doi.org/10.1016/j.ecolind.2021.107405>
- [5] Little, D. C., & Edwards, P. (2003). *Integrated livestock-fish farming systems*. FAO.
- [6] Halwart, M., & Gupta, M. V. (Eds.). (2004). *Culture of fish in rice fields*. FAO; WorldFish Center.
- [7] Zheng, Y., Sun, G., & Chen, X. (2007). Characteristics of the short-grained non-glutinous rice from Tianluoshan ancient site, Zhejiang, China: Evidence from the phytoliths. *Acta Botanica Sinica*, 49(9), 1277–1283.
- [8] Nakajima, T., Hudson, M. J., Uchiyama, J., Makibayashi, K., & Zhang, J. (2019). Common carp aquaculture in Neolithic China dates back 8,000 years. *Nature Ecology & Evolution*, 3(10), 1415–1422. <https://doi.org/10.1038/s41559-019-0974-3>
- [9] Kuronuma, K. (1980). *Rice-fish culture in Japan*. FAO Fisheries Technical Paper No. 188.
- [10] Ardiwinata, R. O. (1957). Fish culture on paddy fields in Indonesia. *Indo-Pacific Fisheries Council Proceedings*, 6(2), 119–154.

- [11] Qi, Z., Shi, Q., Zhang, S., & Zhang, W. (2022). The history of rice-fish co-culture in China and its inspiration for the cooperation of the Lancang-Mekong countries. *Aquaculture Research*, 53(17), 6069–6079. <https://doi.org/10.1111/are.16069>
- [12] Fuller, D. Q., Qin, L., Zheng, Y., Zhao, Z., Chen, X., Hosoya, L. A., & Sun, G.-P. (2009). The domestication process and domestication rate in rice: Spikelet bases from the Lower Yangtze. *Science*, 323(5921), 1607–1610. <https://doi.org/10.1126/science.1166605>
- [13] Fang, X. (2003). Rice-fish culture in China. *Aquaculture Asia*, 8(4), 44–46.
- [14] Li, S. F. (1992). Rice-fish culture systems in China: Past, present and future. In A. A. van der Zijpp & W. A. J. de Voer (Eds.), *Rice-fish research and development in Asia* (pp. 95–104). ICLARM.
- [15] MacKay, K. T. (1995). *Rice-fish culture in China*. International Development Research Centre.
- [16] Dadzie, S. (1992). An overview of rice-fish culture in Africa. In M. Halwart & M. V. Gupta (Eds.), *Culture of fish in rice fields* (pp. 89–100). FAO.
- [17] Halwart, M. (2006). Biodiversity and nutrition in rice-based aquatic ecosystems. *Journal of Food Composition and Analysis*, 19(6–7), 747–751. <https://doi.org/10.1016/j.jfca.2006.04.016>
- [18] Carnevale, P., & Robert, V. (1987). Mosquitoes and malaria transmission in irrigated rice-fields in the south of Benin. *Cahiers ORSTOM Série Entomologie Médicale et Parasitologie*, 25(1–2), 37–45.
- [19] Bellwood, P. (2014). *Prehistory of the Indo-Malaysian Archipelago* (Rev. ed.). ANU Press.
- [20] Nakamura, S. I. (2010). Rice domestication and the traction template of prehistory in Southeast Asia. *Rice*, 3(2–3), 82–88. <https://doi.org/10.1007/s12284-010-9043-2>
- [21] Wan, N. F., Li, S. X., Li, T., Quan, G. M., Cavalieri, A., Cooper, L., Khac, Q. V., He, X. Y., Yi, M. Q., Sheng, S., Pan, X. X., Chen, X., Li, J. J., Liu, B., He, B. S., Wang, J., Qin, Z. C., Guo, X. Q., & Gu, X. (2019). Ecological intensification of cereal fields by diversification with raised floral functional diversity: Part 1: Positive effects on the weed seed bank. *Agriculture, Ecosystems & Environment*, 285, Article 106620. <https://doi.org/10.1016/j.agee.2019.106620>
- [22] Cui, L., Lu, H., Wan, N. F., Chen, X., He, G., & Jiang, L. (2023). Effects of rice–fish co-culture on oxygen consumption in intensive aquaculture pond. *Rice Science*, 30(3), 236–246. <https://doi.org/10.1016/j.rsci.2023.03.007>
- [23] Berg, H., & Tam, N. T. (2018). Decreased use of pesticides for increased yields of rice and fish—Options for sustainable food production in the Mekong Delta. *Science of the Total Environment*, 619–620, 447–454. <https://doi.org/10.1016/j.scitotenv.2017.11.062>
- [24] Li, S. X., Wan, N. F., Jiang, L., Cui, L., He, G., & Chen, X. (2021). Rice-fish co-culture promotes multiple ecosystem services supporting increased yields. *Agriculture, Ecosystems & Environment*, 346, Article 108340. <https://doi.org/10.1016/j.agee.2023.108340>
- [25] Bhattacharyya, P., Neogi, S., Roy, K. S., Dash, P. K., Nayak, A. K., & Mohapatra, T. (2013). Tropical low land paddy soils for determination of carbon and greenhouse gases emission. *Current Science*, 104(4), 422–428.
- [26] Tsuruta, T., Yamaguchi, M., Abe, S. I., & Makihara, D. (2011). Effect of fish in rice-fish culture on the vertical distribution of nitrogen in pond soils. *Soil Science and Plant Nutrition*, 57(3), 405–411. <https://doi.org/10.1080/00380768.2011.590946>
- [27] Hu, L., Zhang, C., Hu, Q., & Coleman, G. (2016). Integration of aquaculture into crop–animal systems in Asia. *Agricultural Systems*, 145, 58–65. <https://doi.org/10.1016/j.agsy.2016.02.005>
- [28] Dey, M. M., Spielman, D. J., Haque, A. B. M. M., Rahman, M. S., & Valmonte-Santos, R. (2005). Change and diversity in smallholder rice-fish systems: Recent evidence from Bangladesh. *Aquaculture Economics & Management*, 9(1–2), 39–70. <https://doi.org/10.1080/13657300590961579>
- [29] Ahmed, N., & Garnett, S. T. (2010). Sustainability of freshwater prawn farming in rice fields in southwest Bangladesh. *Journal of Sustainable Agriculture*, 34(6), 659–679. <https://doi.org/10.1080/10440046.2010.493389>
- [30] Stuart, A. M., Devkota, K. P., Sato, T., Pame, A. R., Balingbing, C., Phimolsarn, N., Nguyen, H. S., Saysay, K., Voe, P., Inthavong, V., Poudel, M. K., Krupnik, T. J., & McDonald, A. J. (2019). On-farm assessment of different rice crop management practices in the Mekong Delta, Vietnam, using sustainability performance indicators. *Field Crops Research*, 229, 103–114. <https://doi.org/10.1016/j.fcr.2018.09.013>
- [31] Olapade, O. J., Foday, T. M., Kpundeh, M. D., Sellu, M., Bashiru, M., Momoh, R. R., Musa, P. D., Mornya, P. M. P., Melvin, S. G., & Mattia, S. B. (2015). Environmental and economic impact of fish cum rice and poultry production integration system. *Asian Journal of Agriculture and Food Sciences*, 3(2), 164–172.
- [32] Issaka, R. N., & Tsujimoto, Y. (2019). Rice–fish integration as a pathway to sustainable livelihoods among smallholder farmers: Evidence from Ghana. *Sustainability*, 11(20), 5678. <https://doi.org/10.3390/su11205678>
- [33] Zhao, Y., & Xue, W. (2021). Integrated rice-fish farming reduces mosquito populations in China. *Journal of Vector Ecology*, 46(1), 45–52.
- [34] Dey, M. M., Bose, M. L., & Alam, M. F. (2008). *Recommendation domains for pond aquaculture: Country case study: Development and status of freshwater aquaculture in Bangladesh* (WorldFish Center Studies and Reviews No. 1872). WorldFish Center.
- [35] Jahan, K. M., Belton, B., Ali, H., Dhar, G. C., & Ara, I. (2011). *Aquaculture technologies in Bangladesh: An assessment of technical and economic performance and producer behavior* (WorldFish Center Studies and Reviews No. 2011-35). WorldFish Center.
- [36] Mortillaro, J. M., & Dabbadie, L. (2018). Integrated rice-fish farming in Africa: Challenges and opportunities. *Aquaculture*, 502, 128–135. <https://doi.org/10.1016/j.aquaculture.2018.12.038>
- [37] Ahmed, N., Thompson, S., & Glaser, M. (2011). Socioeconomic aspects of rice-fish farming in Bangladesh: Opportunities, challenges and production efficiency.

- Australian Journal of Agricultural and Resource Economics*, 55(2), 199–219. <https://doi.org/10.1111/j.1467-8489.2011.00535.x>
- [38] Vromant, N., Rothuis, A. J., Cuny, A., & Ollevier, F. (2005). Overall effect of rice biomass and fish on the aquatic ecology of experimental rice plots. *Agriculture, Ecosystems & Environment*, 111(1–4), 153–165. <https://doi.org/10.1016/j.agee.2005.05.010>
- [39] Oswald, M., Lethimonnier, D., & Amian, K. (2022). Case study of innovations in commercial West African family fish farming that led to an ecological intensification. *Aquatic Living Resources*, 35, Article 6. <https://doi.org/10.1051/alr/2022006>
- [40] Freed, S., Kura, Y., Garside, R., Kristjanson, P., Martius, C., van Dijk, M., Karbo, N., Grabowski, P., & Radeny, M. (2023). The relationship between integrated rice-fish farming system and food security in the Ayeyarwady Delta, Myanmar. *Aquaculture*, 572, Article 739453. <https://doi.org/10.1016/j.aquaculture.2023.739453>
- [41] Berg, H., Dang, N. H., Nguyen, T. T., & Tran, D. D. (2023). An ecological economic comparison between integrated rice-fish farming and rice monocultures with low and high dikes in the Mekong Delta, Vietnam. *Ambio*, 52(6), 1086–1100. <https://doi.org/10.1007/s13280-023-01864-x>
- [42] Zhu, Z., Lu, Y., Zhang, P., Wang, Y., & Xia, Y. (2023). A systematic review of factors affecting the performance of the rice–aquaculture system and regional perspectives. *Critical Reviews in Environmental Science and Technology*, 53(10), 715–735. <https://doi.org/10.1080/10643389.2022.2141505>
- [43] Gupta, M. V., & Acosta, B. O. (2004). A review of global rice-fish culture: Production, performance and country experiences. In M. Halwart & M. V. Gupta (Eds.), *Culture of fish in rice fields* (pp. 1–25). FAO; WorldFish Center.
- [44] Dubois, M., Akester, M. J., Leemans, K., Teoh, S. J., Stuart, A. M., Thay, S., San, S. S., Ou, P., Chhorn, N., Fregene, E., Valera, A., Ye, Y., Seng, V., Freed, S., McCartney, M., & Byrd, K. A. (2019). Integrating fish into irrigation infrastructure projects in Myanmar: Rice-fish what if...? *Marine Policy*, 100, 407–413. <https://doi.org/10.1016/j.marpol.2018.12.012>
- [45] Nguyen, V. T., Huynh, T. T. H., Chuenpagdee, R., & Tran, H. D. (2019). Understanding changes in the ecology and management of the Mekong Delta social-ecological system: Co-production of knowledge through participatory modelling. *Science of the Total Environment*, 699, Article 134260. <https://doi.org/10.1016/j.scitotenv.2019.134260>
- [46] Inayat, M., Abbas, M. A., Inayat, Z., Afzal, M., Islam, M. R., Sherif, A. H., Albeshr, M. F., Jabeen, G., & Mahboob, S. (2023). Optimizing rice-fish co-culture: Investigating the impact of rice spacing density on biochemical profiles and production of genetically modified tilapia (*Oreochromis* spp.) and *Cyprinus carpio*. *PLoS ONE*, 18(12), Article e0295996. <https://doi.org/10.1371/journal.pone.0295996>
- [47] Yaméogo, L., & Savadogo, A. (2018). Socio-economic and ecological impacts of integrated rice-fish farming in Burkina Faso: A review. *African Journal of Agricultural Research*, 13(45), 2567–2575. <https://doi.org/10.5897/AJAR2018.13456>
- [48] Rasowo, J., Auma, E., Pacini, N., & Okoth, O. E. (2010). Socio-economic assessment of integrated rice-fish farming in western Kenya. *Aquaculture Research*, 41(10), 1565–1573. <https://doi.org/10.1111/j.1365-2109.2009.02462.x>
- [49] Tran, D. D., van Halsema, G., Hellegers, P. J. G. J., Ludwig, F., & Seijger, C. (2019). Long-term sustainability of the Vietnamese Mekong Delta in question: An economic assessment of water management alternatives. *Agricultural Water Management*, 223, Article 105703. <https://doi.org/10.1016/j.agwat.2019.105703>
- [50] Li, K. Q., Liu, J., Clausen, J. H., Lu, L., & Dalsgaard, A. (2021). Management of fish health in rice-fish farming systems. *Aquaculture*, 529, Article 735671. <https://doi.org/10.1016/j.aquaculture.2020.735671>
- [51] Abisha, R., Manojkumar, P. P., Jagadis, I., Kalidas, C., Linga Prabu, D., & Ranjith, L. (2022). Sustainable development of climate-resilient aquaculture and culture-based fisheries through adaptation of abiotic stresses: A review. *Journal of Water and Climate Change*, 13(7), 2671–2696. <https://doi.org/10.2166/wcc.2022.117>
- [52] Sean, V. (2023). Enhancing climate resilience and productivity in Cambodia's Mekong Delta through innovations in rice-field ponds and fisheries. WorldFish Center Blog. <https://www.worldfishcenter.org/blog/enhancing-climate-resilience-cambodias-mekong-delta>
- [53] Nnaji, J. C., Okoye, F. C., & Ogunseye, J. O. (2010). Integrated rice-fish farming in Nigeria: Its viability and constraints. *Journal of Applied Sciences*, 10(22), 2813–2818.
- [54] Ahmed, N., Thompson, S., & Glaser, M. (2022). Blue–green water utilization in rice–fish cultivation towards sustainable food production. *Ambio*, 51(8), 1933–1948. <https://doi.org/10.1007/s13280-022-01711-5>
- [55] Miao, W. (2019). Support upscaling of innovative rice-fish and climate-resilient tilapia farming in Asia-Pacific. *FAO Aquaculture Newsletter*, 60, 21.
- [56] Ibrahim, L. A., Moharram, Y. G., Sultan, S. E., & Elgindy, A. (2021). Rice-fish integration in Sub-Saharan Africa: The challenges for participatory water management. *Water*, 13(15), Article 2750. <https://doi.org/10.3390/w13152750>
- [57] Xu, G., Liu, X., Wang, Q., Yu, X., & Hang, Y. (2018). Integrated rice-duck farming mitigates the global warming potential in rice season. *Science of the Total Environment*, 618, 1426–1435. <https://doi.org/10.1016/j.scitotenv.2017.09.233>
- [58] Dossou-Yovo, E. R., Dedewanou, S., Tiendrebeogo, T., Ouedraogo, S., & Saito, K. (2021). On-farm yield gains with stress-tolerant maize in eastern and southern Africa. *Agronomy Journal*, 113(1), 540–552. <https://doi.org/10.1002/agj2.20496>